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An Evaluation of the Petroleum Investment Environment in African Oil-Producing Countries Based on Combination Weighting and Uncertainty Measure Theory

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Abstract: Recognizing that the evaluation of the overseas petroleum investment environment is affected by many uncertain factors and that there are problems with current evaluation methods, this paper proposes a mathematical evaluation model of an overseas oil resources investment environment, based on a combination of the weighting and uncertainty measure theory. Combining international investment environment theory with the characteristics of the petroleum industry, this paper establishes an evaluation index system for the overseas petroleum investment environment and the linear uncertainty measure function of each index. Using the subjective weight obtained using an analytic hierarchy process together with the objective weight obtained using the entropy weight method, the optimal weight of each evaluation index was obtained using minimum relative information entropy. A multi-index evaluation matrix of the top 12 oil-producing countries in Africa was calculated. Finally, the credible degree recognition criterion was used to judge the order and level of the oil investment environment. This model provides an effective method for the evaluation of the overseas petroleum investment environment. The results show that Nigeria and Angola have the best investment climate, followed by Algeria, Egypt, and Libya. In general, Africa is an important strategic partner of China and is rich in oil resources. Although Africa's oil industry is fraught with complex challenges and headwinds, challenges also present opportunities.

Keywords: Africa; petroleum investment; entropy weight; information entropy; uncertainty measure

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1. Introduction

In recent years, as a result of the rapid development of China's domestic production and relatively slow oil exploration and development, China's domestic dependence on crude oil imports has been increasing. At the same time, as the United States develops its shale oil and gas industry, making the United States the world's largest energy exporter for a time, China's consumption has been increasing. Although China is the world's sixth largest oil producer, in 2018 it surpassed the United States as the world's largest oil importer. China's imports of crude oil increased year by year during the 13th five-year plan period, and its dependence on foreign oil also increased year by year. The import volume of crude oil in 2016 was 380 million tons, with an external dependency of 65.4%; the import volume of crude oil in 2017 was 420 million tons, with an external dependency of 68.4%; the import volume of crude oil in 2018 was 462 million tons, with an external dependency of 70.8%; and the import volume of crude oil in 2019 was 506 million tons, with an external dependency of 72.6%. As a result of the impact of COVID-19, international oil prices fell sharply in 2020, so China's crude oil imports in 2020 still grew, with an import volume of crude oil in 2020 of 540 million tons and an external dependency of 73.5% (Figure 1) [1,2].

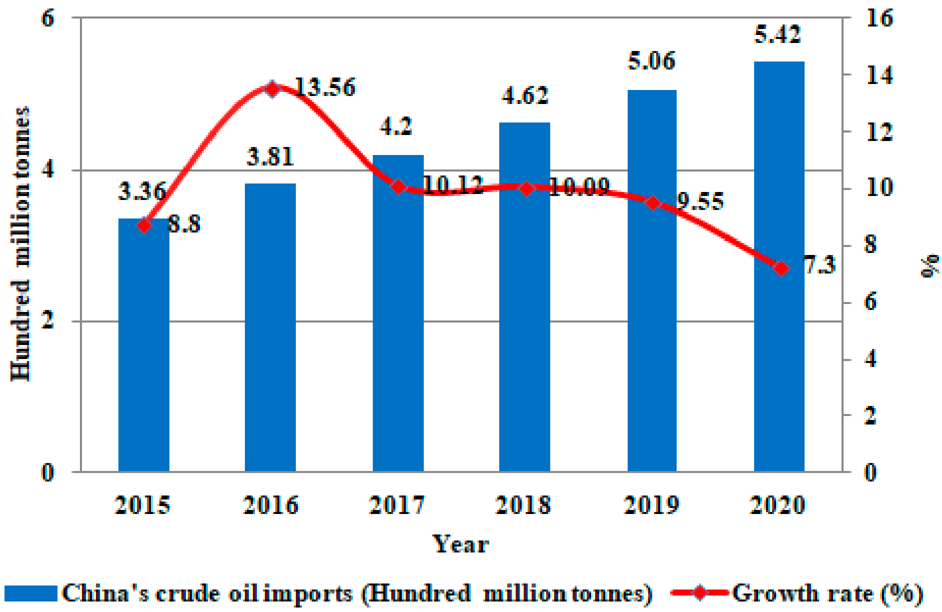

Figure 1. China's crude oil import statistics and growth 2015–2019 [1].

As a large oil-consuming country, China's oil consumption increases year by year, and its growth rate fluctuates. According to the latest data released by the China Federation of Petroleum and Chemical Industries, the apparent domestic consumption of crude oil reached 696 million tons in 2019, an increase of 7.4% year-on-year, representing an increase of 0.5 percentage points over 2018. As a result of the COVID-19 outbreak, the global economy deteriorated sharply, the industrial supply chain suffered a severe setback, and the growth of crude oil consumption slowed down. The apparent domestic consumption of crude oil is now 736 million tons, up 5.6% from 2019, the growth having slowed in a year [3–5].

Africa is an important strategic partner of China and is rich in oil resources. At the end of 2020, Africa had proven oil reserves of nearly 125.1 billion barrels, which represented 7.2% of the world's total proven oil reserves and is one of the eight largest oil-producing regions in the world. Africa's oil production and exports have grown rapidly in the past decade, playing an increasingly important role in the international energy landscape. As an important source of oil imports, the China–Africa oil trade has developed gradually since 1992. In the early stages of cooperation, China mainly imported oil from Angola, Libya and some other countries, with a total of 498,500 tons imported in the first year. The ever-expanding oil trade between China and Africa has laid a good foundation for China–Africa cooperation [6]. After the "Forum on China–Africa Cooperation", the two sides stepped up their cooperation in oil and other energy fields. In 2017, Africa was the second largest source of crude oil imports in China's oil trade, after the Middle East, accounting for 20% of China's total crude oil imports. On a country-by-country basis, 14 of the 44 countries of import origin are African and it is the region with the largest number of import origin countries. There is rapid growth in the China–Africa oil trading relationship. Therefore, given the increasing globalization of the world economy, the international political situation, and the volatility of the oil market, as well as China's increasing demand for oil and its increasing annual import volume and external dependence year by year, it is appropriate that China attaches great importance to Africa's oil resources. Systematic research on the investment environment of the African oil industry will lower the risks and increase the success of our enterprises when seeking to import oil and will also support China's energy security and develop China–Africa relations for mutual benefit [7–9].

With the gradual establishment of the global free trade and open economy system, experts and scholars from many institutions at home and abroad have conducted in-depth research in the field of overseas oil investment. Most of the initial domestic research focused on the risks of overseas oil investment. For example, Cai [10], in a discussion of the risk issues for Chinese oil enterprises, Zhang [11], in a risk analysis of overseas investment of Chinese oil enterprises, and Wang [12] in the overseas investment risk of Chinese petroleum enterprises and its countermeasures, respectively analyzed the political, policy, and economic (etc.) risks encountered in the process of overseas oil investment, and discussed how Chinese petroleum enterprises should take effective measures to avoid and reduce the risks associated with overseas investment. Ye [13] studied the mineral resources of the Democratic Republic of the Congo and concluded that the investment environment in that country needed to be improved. Feng et al. [14] studied Zambia's mining development and mining investment environment and concluded that Zambia's mining investment had good prospects. In recent years, with the rapid development of the theory and technology of mathematical comprehensive evaluation models, mathematical models are increasingly used to evaluate quantitatively the investment environment of the overseas petroleum industry. O'Regan and Moles [15] firstly determined the weight of each factor based on an analytic hierarchy process (AHP), and then, according to the principle of fuzzy relation synthesis, comprehensively graded the overseas investment environment based on many factors. Bo et al. [16] considered the dual attributes of economic attractiveness and investment risk of the investment environment of resource countries, established a decision making optimization model using a bivariate decision making matrix to realize the environmental goal of transnational investment of oil companies via economic attractiveness and risk indices. Li and Li [17] used fuzzy comprehensive evaluation, cluster analysis and principal component analysis to develop a comprehensive evaluation model for the transnational investment environment of Chinese petroleum enterprises. Mu and He [18] used the entropy weight method and matter–element model to evaluate the oil investment environment of five major oil-producing countries in Africa. Duan et al. [19] constructed a fuzzy comprehensive evaluation model of the overseas energy investment environment based on entropy weight. Lin [20] used principal component analysis to produce a comprehensive evaluation of integration management and cooperation among 15 African countries. Liu [21] used AHP to carry out a comprehensive evaluation of the mining investment environment in five central and southern African countries.

To sum up, at present there is no unified evaluation index system, and evaluation of the overseas oil investment environment is influenced by many factors, with each factor influencing other factors, resulting in complex uncertainty. Bringing the final evaluation result more in line with reality will make the forecasting result more accurate, therefore this paper proposes a combination weighting–uncertainty measure model to achieve an overall evaluation of the overseas oil investment environment. The uncertainty measure theory is an ideal mathematical tool because it is able to link various kinds of uncertainty information and comprehensively consider uncertainty factors, such as the fuzziness and complexity of factors impacting the overseas oil investment environment. In the process of applying the uncertainty measure model to a comprehensive evaluation, the determination of the weight plays a decisive role in the final result. However, at present, in the calculation of the weight of evaluation indices, methods such as the subjective expert consultation method and the analytic hierarchy process are used to determine the weight of the index; thus, subjective factors have a greater influence. If insufficient consideration is given to the index information of the evaluation object, it can be easy to deviate from objective reality leading to formation of a significant evaluation bias. On the other hand, if the objective entropy weight method is used to determine the weight of the index, the result of evaluation will be more accurate than using subjective evaluation, but it only considers the significance of data, and does not consider the reality of the evaluation index. In this paper, in order to make the result of evaluation as close as possible to reality, the weighting in the uncertainty measure model is optimized based on minimum relative information entropy to minimize the information loss and make the result of comprehensive evaluation more reasonable and reliable. In order to verify the validity of the model, the oil investment environment of African oil-producing countries was evaluated by the combination weighting–uncertainty measure model. This model provides a new approach to the evaluation of overseas petroleum resources investment environment.

2. Calculation of Combination Weight

For petroleum investment environment modeling, each index weighting is a key point in the evaluation process. The common weighting methods can be classified into two categories: the objective weighting method and the subjective weighting method. Objective weighting methods, such as the entropy weight method and the principal component analysis method, determine index weight based on actual data, using a specific algebraic equation [22]. Subjective weighting methods, for example, AHP, the Delphi method, and the expert grading method, involve a decision maker determining the attribute weight according to the importance degree of the index. The evaluation results are therefore often highly subjective.

In order to minimize the arbitrariness of subjective weighting and give consideration to the preference of decision makers for index weighting, our evaluation of the overseas petroleum investment environment combines the entropy weight method and AHP, improving the evaluation and making the results more accurate and reliable [23,24].

2.1. Determination of the Objective Weight–Entropy Weight Method

The index system generally constructed includes qualitative and quantitative indices, which need to be, respectively, weighted. To determine the weight of the qualitative index by entropy value, the membership degree of the index is taken as the basis. The entropy value and the entropy weight calculation formulae of the qualitative index are as follows:

$$E_i = \frac{\sum\limits_{j=1}^{n} \ln x_{ij}}{\ln n} \tag{1}$$

$$w_i = \frac{1 - E_i}{\sum\limits_{i=1}^{m} (1 - E_i)} \tag{2}$$

where E_i is the entropy value of evaluation index i, j is the criterion layer, n is the number of criterion layers in the system, x_{ij} is the mutual membership of the index, w_i is the weight of the i evaluation index, and m is the number of the evaluation index.

The formula for calculating the weight of the quantitative index using the entropy weight is different from that of the qualitative index. In the calculation of the weight of the quantitative index using the entropy weight, because of the difference of the units between the indices, all the original data should first be standardized. The entropy value and the entropy weight calculation formula of quantitative index are as follows:

$$v_i = 1 + \frac{1}{\lg n} \sum_{j=1}^{n} x_{ij} \lg x_{ij} (j = 1, 2, \cdots, n) \tag{3}$$

$$w_i = v_i / \sum_{i=1}^{m} v_i \, (i = 1, 2, \cdots, m) \tag{4}$$

where x_{ij} is the proportion of evaluation index i in criterion layer j and v_i is the peak value of evaluation index i.

2.2. Determination of the Subjective Weight–Analytic Hierarchy Process

Determining the importance scale between the indices is the basis for establishing the weight judgment matrix, and it is also the first step of AHP. At present, there are four types of importance scale values in common use in China and these are shown in Table 1. Selecting the best scale for the evaluation of the overseas oil investment environment can make the evaluation results more realistic. The order of performance for the above four scales from small to big is: 1–9 scale, index scale, (10/10–18/2) scale and (9/9–9/1) scale, so the best performance (9/9–9/1) scale value was chosen [24,25].

Table 1. Definition and description of importance scale.

Grade	Definition	1–9 Scale	Index Scale	9/9–9/1	10/10–18/2
1	The element i is more important than the element j	1	9^0	9/9	10/10
3	The element i is slightly more important than the element j	3	$9^{1/9}$	9/7	12/8
5	The element i is slightly obviously more important than the element j	5	$9^{3/9}$	9/5	14/6
7	The element i is strongly more important than the element j	7	$9^{6/9}$	9/3	16/4
9	The element i is extremely more important than the element j	9	$9^{9/9}$	9/1	18/2
Even number	An even number represents the corresponding scale between two grades				

Overseas investment decision makers use judgement to determine the relative importance of each index and determine the weight judgment matrix $\overline{R}$ according to the actual situation:

$$\overline{R} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{5}$$

After scoring and obtaining the judgment matrix according to the importance scale table, the eigenvector p corresponding to the largest eigenvalue $\lambda_{\max}$ in the matrix is defined as the initial weight of the index, and the equation is

$$pw = \lambda_{\max} w \tag{6}$$

2.3. Determination of Combination Weight–Minimum Relative Information Entropy

The subjective weight w_{1i} and the objective weight w_{2i} can be combined to obtain the combination weight $w_i(i = 1, 2, \cdots, m)$, and w_i, w_{1i} and w_{2i} should be as close as possible. According to the principle of minimum relative information entropy,

$$\min F = \sum_{i=1}^{m} w_i(\ln w_i - \ln w_{1i}) + \sum_{i=1}^{m} w_i(\ln w_i - \ln w_{2i}) \tag{7}$$

where F is information entropy, $\sum\limits_{i=1}^{m} w_i = 1, w_i > 0, i = 1, 2, \cdots, m$.

The above optimization problem is solved using the Lagrange multiplier method, to obtain the combined weight equation:

$$w_i = \frac{(w_{1i} \cdot w_{2i})^{1/2}}{\sum\limits_{i=1}^{m} (w_{1i} \cdot w_{2i})^{1/2}} (i = 1, 2, \cdots m) \tag{8}$$

Equation (8) states that, in all the combined weights of the satisfiable Equation (7), the least information is required to obtain the geometric mean, and the other combination weights are taken to add the information that we do not actually obtain [25–27].

3. Uncertainty Measure Theory

The universe of n objects to be evaluated and m one-way evaluation index spaces are set as $X = \{x_1, x_2, \cdots, x_n\}$ and $I = \{I_1, I_2, \cdots, I_m\}$, respectively, and the evaluation space is $U = \{C_1, C_2, \cdots, C_p\}$, where C_k is the k evaluation grades, and the k degree is higher than the $k+1$ degree, namely $C_k > C_{k+1}$. The observed value x_{ij} of the object x_i under the index I_j determines x_i in C_k degree of the k evaluation level as $\mu_{ijk} = \mu(x_{ij} \in C_k)(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m; k = 1, 2 \cdots, p)$, so μ_{ijk} is a measure of the degree. If μ_{ijk} meets the three measure criteria of "non-negative, unitary and additivity", then the matrix composed of μ_{ijk} is the evaluation matrix of a single-index measure:

$$(\mu_{ijk})_{m \times p} = \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i1p} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2p} \\ \vdots & \vdots & \vdots & \vdots \\ \mu_{im1} & \mu_{im2} & \cdots & \mu_{imp} \end{bmatrix} \tag{9}$$

When the value of each index and the evaluation level are determined, the weight $w_j(0 \le w_j \le 1, \sum\limits_{j=1}^{m} w_j = 1)$ of each index should be given. Based on the approach of combined weighting using the minimum relative information entropy, the optimal index weights obtained by balancing and optimizing the subjective and objective weight values are calculated, then the multi-index comprehensive measure $\mu_{ik} = \sum\limits_{j=1}^{m} w_j \mu_{ijk}(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m; k = 1, 2 \cdots, p)$ is calculated, where $0 \le \mu_k \le 1, \sum\limits_{k=1}^{p} \mu_{ik} = 1$, so μ_{ik} is the uncertainty measure, $\{\mu_{i1}, \mu_{i2}, \cdots, \mu_{ip}\}$ is the evaluation vector of the multi-index comprehensive measure for x_i.

The final comprehensive evaluation level is determined using the credible degree recognition criterion. λ represents the credible degree ($\lambda \ge 0.5$, often $\lambda = 0.6$ or 0.7). When $k_0 = \min\left(k : \sum\limits_{l=1}^{k_p} \mu_{il} \ge \lambda, 1 \le l \le k\right)$, x_i is considered to belong to the C_{k_0} of the k_0 evaluation level.

In addition, to determine the x_i evaluation level, sometimes the order of importance for x_i is required. If $C_1 > C_2 > \cdots > C_p$, the value of C_{l_0} is set as n_{l_0}, so $n_{l_0} > n_{l+1}$, and $q_{x_i} = \sum\limits_{l=1}^{p} n_l \mu_{il}$, where q_{x_i} is the uncertainty importance of the evaluation factor x_i, $q = \left\{q_{x_1}, q_{x_2}, \cdots, q_{x_p}\right\}$ is called the uncertainty importance vector, which can be used to obtain the order of importance for x_i activity [28–34].

4. A Case

Africa, as the world's second largest continent by area and population after Asia, includes 56 countries and regions. According to the country investment guide data from the National Bureau of Statistics of some African countries, the World Bank, and the Ministry of Commerce of the People's Republic of China, Africa's total population is about 1.286 billion, of which Nigeria and Ethiopia each account for more than 100 million. Africa's nominal GDP reached USD 2.2 trillion in 2020, and although most of the world's economies experienced negative growth in 2020 as a result of COVID-19, Africa's economic performance was strong, with nearly half of the economies recording positive growth. Among them, the growth rate of Egypt's economy was 19.68%, the fastest in Africa, and the second fastest was Guinea, with a growth rate of 12.32%. As a result of political turmoil and a tough business climate, the fastest economic downturn in Africa was seen in Libya, where GDP reduced by 45.23% in 2020 [1,35,36].

Africa is very rich in energy and resources, and thus has a "world oil depot" reputation. Compared to other regions, Africa has very large oil reserves in more than 20 countries. According to the *bp Statistical Review of World Energy 2021*, the top five proven oil reserves in Africa by the end of 2020 were in Libya (6.3 billion tons, 48.4 billion barrels, total share 2.8%), Nigeria (5 billion tons, 36.9 billion barrels, total share 2.1%), Algeria (1.5 billion tons, 12.2 billion barrels, total share 0.7%), Angola (1.1 billion tons, 7.8 billion barrels, total share 0.4%), and South Sudan (500 million tons, 3.5 billion barrels, total share 0.2%) (Figure 2) [1,35,36].

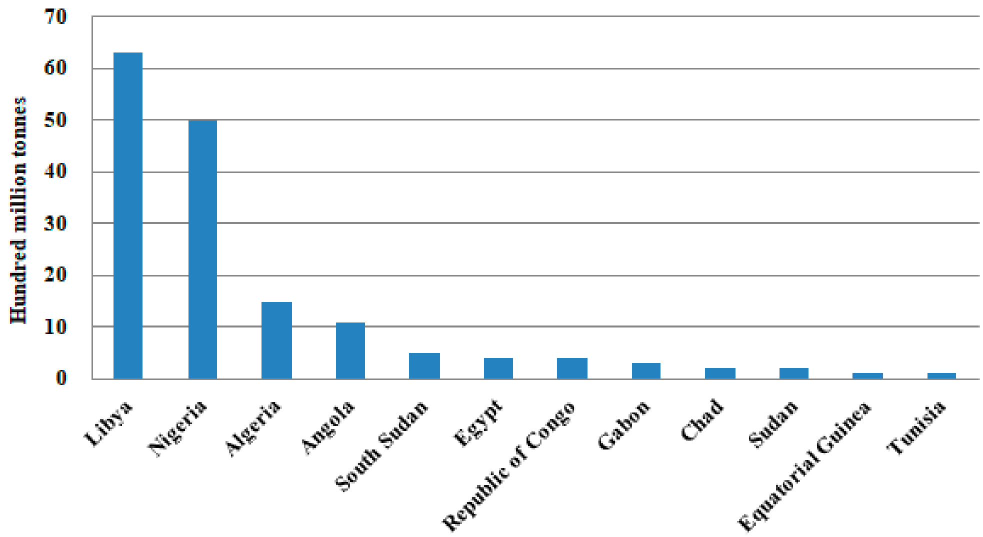

Figure 2. Top 12 countries with proven oil reserves in Africa [36].

As an important source of China's oil imports, Africa was the second largest source of crude oil imports in China's oil trade in 2017, second only to the Middle East, and accounted for 20% of China's total crude oil imports. On a country-by-country basis, 14 of the 44 countries of origin for imports are African countries and it is the region with the largest number of countries of origin for imports into China. China–Africa oil cooperation shows rapid growth. However, while political and regional security in Africa has been generally stable since the mid-1990s, in recent years there have been more frequent political risks, such as the "Arab Spring" in 2011, the north–south split in Sudan, Nigeria's "Boko Haram" terrorist activities, etc. These all pose a serious threat to the development of business related to oil resources. In addition, although some countries are currently stable, they have long been in a state of "Strongman Politics". Their social governance has not yet entered a stable period, and various types of social conflicts are prominent, so the risks of potential coups, civil wars, separatism, terrorism, etc., cannot be underestimated [1,2,7,8]. Therefore, in order to provide a useful reference for Chinese enterprises wishing to invest in the African oil field, it is necessary to carry out a comprehensive evaluation of the key African oil countries.

4.1. Construction of the Evaluation Index System

As an international investment environment, the petroleum industry not only involves specific countries and regions, but also wider factors relating to the petroleum industry. Thus, when analyzing the investment environment of the petroleum industry, we should not only consider the influence factors of the traditional international investment environment, but also consider the resource endowment factors of the resource country in question. Therefore, in order to comprehensively and objectively understand the investment environment of the overseas oil industry, the relevant literature was collected and analyzed. To capture the actual situation in Africa, we used accepted classification rules and data published by authoritative institutions, such as the World Bank, as the basis for the evaluation [17,18,20,35,37–39], selecting six factors related to resource endowment, political stability, economic development level, and economic stability.

The classification standard and valuation of each index are shown in Table 2. According to the classification standard and evaluation objectives, the risk was divided into four levels: I, II, III and IV, which reflect excellent, good, medium and poor, respectively. The index data for the oil investment environment in selected African countries are shown in Table 3.

Table 2. Evaluation indices and classification standard for investment environment evaluation in African oil-producing countries.

Evaluation Index		Evaluation Level			
		Excellent (C_1)	Good (C_2)	Medium (C_3)	Poor (C_4)
Resource endowment	Proved reserves/thousand million barrels (x_1)	40–60	20–40	5–20	0–5
	Production/million tons (x_2)	100–120	80–100	40–80	0–40
Political stability	Unemployment rate/% (x_3)	7–8	8–9	9–11	11–13
	Military expenditure/% of GDP (x_4)	0–1	1–2	2–4	4–8
Economic development level	GDP per capita/current US $ (x_5)	10,000–14,000	6000–10,000	4000–6000	1000–4000
Economic stability	GDP Growth/annual % (x_6)	>5	3–5	0–3	<0

Table 3. Evaluation index data for each African oil-producing country.

Evaluation Index		Algeria	Angola	Chad	Republic of Congo	Egypt	Equatorial Guinea	Gabon	Libya	Nigeria	South Sudan	Sudan	Tunisia
Resource endowment	Proved reserves/thousand million barrels	12.2	7.8	1.5	2.9	3.1	1.1	2.0	48.4	36.9	3.5	1.5	0.4
	Production/million tons	57.6	64.5	6.6	15.8	30.0	7.5	10.4	18.3	86.9	8.4	4.2	1.7
Political stability	Unemployment rate/%	11.4	31.6	2.3	10.3	7.3	9.2	20.5	18.63	33.3	12.7	17.7	17.8
	Military expenditure/% of GDP	6.7	1.6	3.1	3.4	1.2	1.3	1.8	3.7	0.6	3.6	1.1	2.9
Economic development level	GDP per capita/current US $	3310	1896	614	2092	3548	7157	6991	3700	2097	748	595	3320
Economic stability	GDP Growth/annual %	−5.5	−4.0	−0.9	−7.9	3.6	−4.9	−1.3	−31.3	−1.8	−3.6	−1.6	−8.6

Data source: 2020 Statistical data of World Bank collated, https://data.worldbank.org.cn/, accessed on 27 October 2021 [35].

4.2. Determination of Index Weights

In our study, firstly, the weight values of all the indices in the comprehensive evaluation index system were calculated using the subjective AHP. Then, the weight values of all indices were calculated using the objective entropy weight method (taking Algeria as an example). Finally, combining the index weights obtained using AHP and the entropy weight method, respectively, in accordance with the principle of minimum relative information entropy, all index weights in the comprehensive evaluation index system were obtained using the Lagrange multiplier optimization method. The final calculation is shown in Table 4.

Table 4. Index weights.

Evaluation Index	AHP	Entropy Weight Method	Minimum Relative Information Entropy
x_1	0.04	0.16	0.10
x_2	0.11	0.13	0.16
x_3	0.09	0.18	0.17
x_4	0.12	0.18	0.19
x_5	0.24	0.18	0.27
x_6	0.40	0.18	0.11

4.3. Single Index Function of Uncertainty Measure

Based on the widely used linear uncertainty construction method, the measure function of each rationality index was constructed according to the rationality index and classification standard of the investment environment evaluation data of the African oil-producing countries shown in Table 2 (Figure 3).

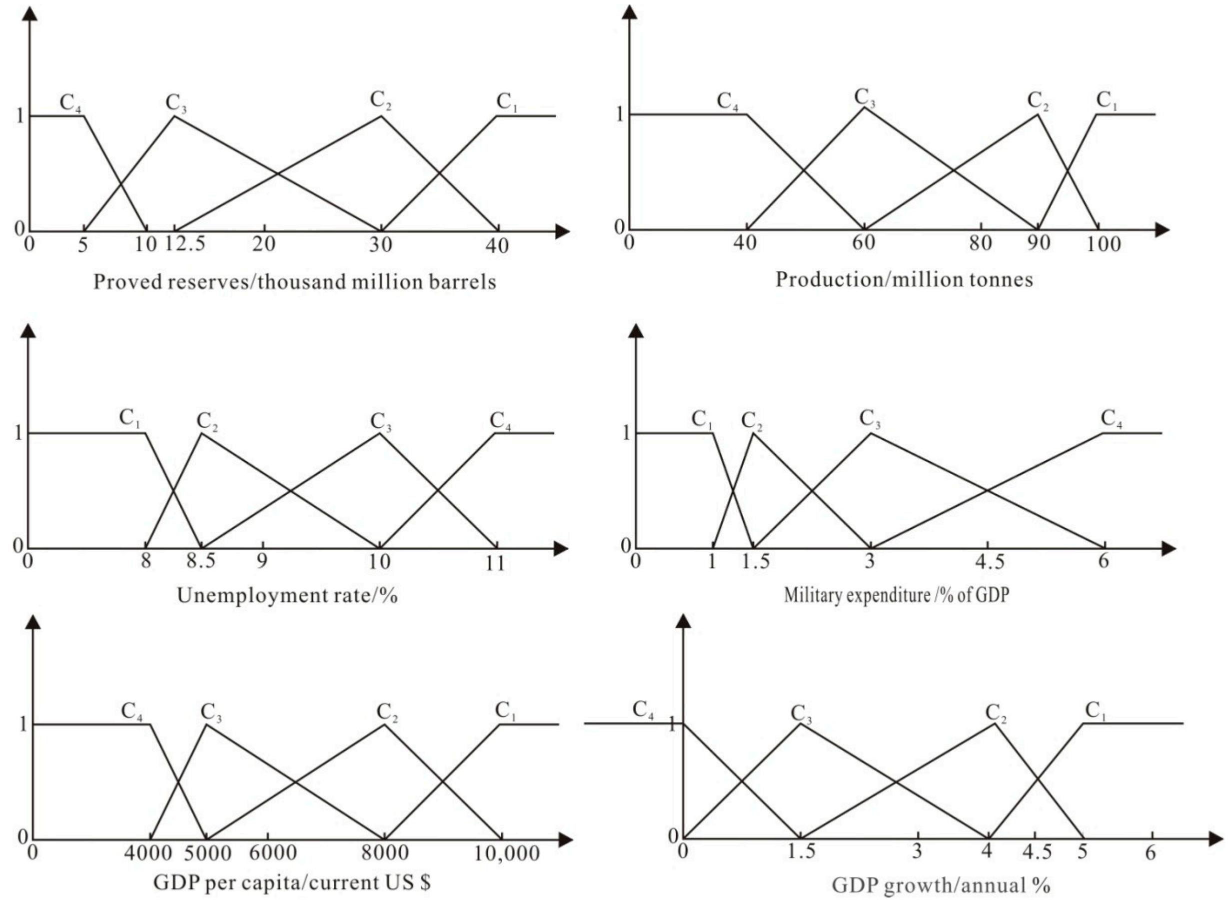

Figure 3. Single index measure function of each single index in evaluation index system.

Based on the single index measure function constructed in Figure 1 and the specific values of the survey of evaluation indices in Algeria in Table 2, the evaluation matrix of single index measure in Algeria can be obtained as follows:

$$\mu_{A_1} = \begin{bmatrix} 0 & 0 & 0.96 & 0.04 \\ 0 & 0 & 0.88 & 0.12 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10}$$

4.4. Calculation of Multi-Index Measure Evaluation Matrix

Based on the optimal combination weight of each evaluation index in the comprehensive evaluation index system calculated using the combination weight method of minimum relative information entropy, the weight of each evaluation index in Algeria $\{w_1, w_2, w_3, w_4, w_5, w_6\} = \{\ 0.10 \quad 0.16 \quad 0.17 \quad 0.19 \quad 0.27 \quad 0.11\ \}$, and, according to the single index measure matrix and the multi-index measure calculation formula, Algeria's multi-index measure vector is $\mu_1 = \varpi_1 \cdot \mu_{A_1} = [\ 0 \quad 0 \quad 0.24 \quad 0.76\ ]$.

4.5. Credible Degree Recognition

Credible degree λ is taken to be 0.6, k_0 = 1.00 > 0.6; that is, Algeria's level is C_3. Eleven other countries were evaluated in the same way. The results of the evaluation are shown in Table 5.

Table 5. Evaluation of the investment environment of African oil-producing countries based on the uncertainty measure model of combination weighting.

Country	Comprehensive Uncertainty Measure				Evaluation Result
	C_1	C_2	C_3	C_4	
Algeria	0	0	0.24	0.76	C_4
Angola	0	0.19	0.18	0.63	C_4
Chad	0.16	0	0.17	0.67	C_4
Republic of Congo	0	0	0.25	0.75	C_4
Egypt	0.25	0.14	0.02	0.59	C_4
Equatorial Guinea	0.06	0.34	0.13	0.47	C_4
Gabon	0	0.28	0.11	0.61	C_4
Libya	0.11	0	0.12	0.77	C_4
Nigeria	0.26	0.16	0.02	0.56	C_4
South Sudan	0	0	0.12	0.88	C_4
Sudan	0.12	0.03	0	0.85	C_4
Tunisia	0	0.01	0.16	0.83	C_4

4.6. Order-Arranging of Favorable

According to the order formula, because $C_1 > C_2 > C_3 > C_4$, take $n_l = 10 - 2q$, where $1 \leq q \leq 4$, then $q = \{q_1, q_2, q_3, \cdots, q_{12}\} = \{\ 2.48 \quad 3.12 \quad 3.30 \quad 2.50 \quad 4.10 \quad 3.98 \quad 3.34 \quad 2.90 \quad 4.24 \quad 2.24 \quad 2.84 \quad 2.36\ \}$. The ranking of the oil investment environment in 12 African countries from large to small is: Nigeria, Egypt, Equatorial Guinea, Gabon, Chad, Angola, Libya, Sudan, Republic of Congo, Algeria, Tunisia and South Sudan.

5. Analysis of Africa's Oil Investment Environment

Under the influence of the epidemic and energy transformation, Africa's production experienced the greatest decline in 2020, when overall production dropped by 18.7%. In 2020, oil production in Africa was 327.3 million tons, and the top 12 major oil-producing countries were Nigeria, Angola, Algeria, Egypt, Libya, Republic of Congo, Gabon, South Sudan, Equatorial Guinea, Chad, Sudan and Tunisia, their combined production accounting for 95% of Africa's total oil production. At the end of 2020, Africa's total proven oil reserves stood at 125.1 billion barrels, and the proven reserves of its top 12 major oil-producing countries accounted for 97% of Africa's total proven reserves [36]. Therefore, the evaluation of the investment environment of the oil industry in the top 12 oil-producing countries in Africa is representative and instructive for oil trade and oil security between China and Africa.

According to the evaluation results, when China invests in the African oil industry, it should give priority to Nigeria and Angola, followed by Algeria, Egypt and Libya, and so on. Investment in these countries should also focus on the country's extreme indices, such as the rising trend of civil violence and political confrontation in Africa in recent years. Ethnic and armed conflicts have become more common, such as in Libya, South Sudan, Central Africa, Republic of Congo, and Nigeria. Government governance as a whole is among the lowest in the world, and the public service provision is inadequate. In Africa, employment, education, health care, public transport, roads, and housing are all negative compared to other countries, and Sudan is now the most developed country in Africa. The two disadvantages of African countries are high political and economic risks, and high operational risks; whereas the two main advantages are the advantageous oil and gas cooperation terms, which are the best in the world. As some African countries do not have an existing oil and gas industry, there is scope to agree mutually advantageous terms. Africa and China enjoy good political relations and strong economic complementarity, which are our two key advantages.

Over the years, China has adhered to a principle of equal cooperation for oil development in Africa, taking mutual benefit and win-win as its goal, and working for the benefit of the local society, thus further cementing the traditional friendship between China and Africa. China's cooperation with African oil-producing countries is based on its deep financial strength and begins with active assistance for infrastructure construction, so as to win the support and understanding of local governments and people.

In general, Africa is rich in oil and gas resources, and African governments have been active in opening up their petroleum industries and formulating policies to support foreign investment in order to develop their own industries and promote the development of their economies. For example, Nigeria's long-delayed *Petroleum Industry Bill*, which was finally approved by the National Assembly and is expected to become law by the end of the year, will create a favorable investment environment for Nigeria's oil and gas industry. Angola and neighboring Zambia have signed a USD 5 billion memorandum of understanding to study the feasibility of building a pipe between the port city of Lobito in Angola and Lusaka, the capital of Zambia, which is expected to cost about USD 5 billion. At the same time, the international community has been of great help to Africa's political, military and economic sectors. For example, the Qatar Petroleum company, together with its partners, plans to invest about USD 7 billion in Angola over the next four years, for exploration, production, oil refining, and other purposes. In view of the economic burden on African countries which has been aggravated by COVID-19, on the basis of the implementation of the G20 debt relief initiative, China will cancel the interest-free loans to Africa by the end of 2020 under the Forum on China–Africa Cooperation. In short, Africa's oil investment environment is more positive than negative, with more opportunities than challenges.

6. Conclusions

As the second largest source of crude oil imports in China's oil trade, Africa plays a vital role in China's oil security. Therefore, in order to comprehensively and objectively understand and analyze the investment environment of the oil industry in African oil-producing countries, this paper systematically studied the investment environment of the petroleum industry in African oil-producing countries, and the main results were as follows:

(1) Based on the characteristics of overseas oil investment, an index system for the comprehensive evaluation of the overseas oil investment environment was constructed, and the uncertainty measure theory was applied in this process. The weighting of the multi-level index system was determined based on the combination weighting method of minimum relative information entropy. The results of the evaluation can effectively overcome the shortcomings of the single subjective weighting in terms of randomness and fuzziness, and the fact that the single objective weighting does not take into account the actual situation of the evaluation index. This makes the weight assignment more realistic and provides a new method for the evaluation of the overseas petroleum investment environment.

(2) The oil investment environment of the top 12 oil-producing countries in Africa was comprehensively evaluated based on the combination weighting–uncertainty measure evaluation model. The multi-index measure evaluation matrix of the top 12 oil-producing countries in Africa was calculated, and the oil investment environment of the top 12 oil-producing countries in Africa was classified according to the credible degree recognition and ordered. The result of the evaluation is basically consistent with the facts.

(3) Under the influence of the epidemic and energy transformation, the proven reserves of many oil companies have been greatly reduced. However, the search for new oil and gas production reserves has become an urgent task for the energy industry, and Africa, as one of the eight largest oil-producing regions in the world, has attracted much oil and gas capital because of its resource endowment and unique advantages. Along with the discovery of a series of oil and gas reserves, the investment in infrastructure in Africa has greatly increased, and the related technologies and services have also made excellent progress, paving the way for the development of the oil and gas industry.

In this paper, an evaluation model of overseas oil investment environment based on the combination weighting–uncertainty measure theory was established for the first time and applied in the example. However, because the evaluation of the overseas oil investment environment is influenced by many factors, and each factor influences the others, leading to complex uncertainty, the evaluation model needs to be constantly studied and improved to enhance the universal applicability and precision of the method and achieve an accurate evaluation of the overseas oil investment environment.

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